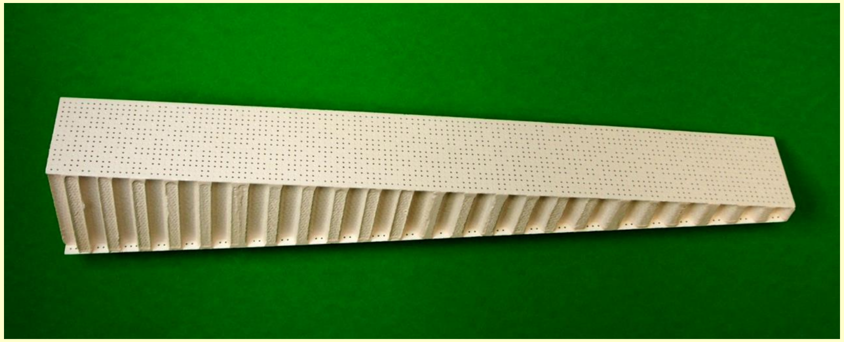
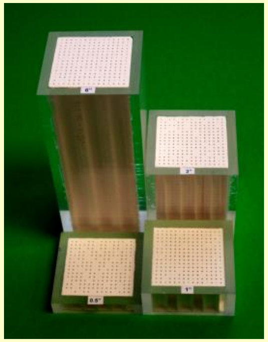
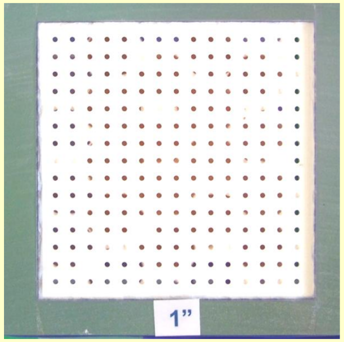
Compact, Lightweight, Ceramic Matrix Composite Based Acoustic Liners for Reducing Subsonic Jet Aircraft Engine Noise

J. Douglas Kiser, Christopher J. Miller, Lennart S. Hultgren, and Joseph E. Grady
NASA Glenn Research Center, Cleveland, OH

Michael G. Jones
NASA Langley Research Center, Hampton, VA



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Research Supported by the NASA Fundamental Aeronautics Program--Fixed Wing Project

Introduction

- Researchers in the Ceramics Branch and the Acoustics Branch at NASA GRC are collaborating with Structural Acoustics Branch researchers at NASA LaRC to investigate and develop high temperature capable oxide fiber/oxide matrix ceramic matrix composite (CMC) based acoustic liners for turbofan core noise reduction.
- Such liners offer the potential for increased durability and weight reduction (in comparison with metallic liners).

Need to Reduce Perceived Community Noise Attributable to Aircraft

Background/Problem

NASA and FAA Working w/Industry and Academia to Reduce Aircraft Noise, Emissions, and Fuel Burn

U.S. National Aeronautics Goals

Technology Benefits*	Technology Generations (Technology Readiness Levels: 4-6)		
	FAA CLEEN	NASA ERA	NASA FA FW
	N+1 (2015)	N+2 (2020)**	N+3 (2025)
Noise (cumulative margin rel. to Stage 4)	-32 dB	-42 dB	-71 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy Consumption*** (rel. to 2005 best in class)	-33%	-50%	-60%

* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size. N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines; N+2 values are referenced to a 777-200 with GE90 engines.

** ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015.

*** CO_2 emission benefits depend on life-cycle CO_{2e} per MJ for fuel and/or energy source used.

Compact, Lightweight, Ceramic Matrix Composite Based Acoustic Liners for Reducing Core Noise

Background/Problem

- Trend toward increased core noise levels as aircraft engines evolve over the next decade.
- As fan and jet noise components are reduced, the importance of core (combustor, turbine) noise increases.
- Core noise could limit the total noise reduction potential of new ultra-high bypass systems.
- Thus, NASA is investigating core noise in a Fixed Wing Project task (Refr. 1-5) focused on:
  - understanding the nature of core noise and its level of importance (contribution to overall engine noise), and
  - means of reducing core noise.
- This liner development effort supports that task.

References

1) “Core Noise—Increasing Importance,” Lennart S. Hultgren, NASA ARMD Fundamental Aeronautics Program Technical Conference, Cleveland, OH, March 15-17, 2011.

2) “Core Noise Reduction,” Lennart S. Hultgren, Acoustics Technical Working Group Meeting, Hampton, VA, October 18-19, 2011.

3) “Core-Noise Research,” Lennart S. Hultgren, NASA ARMD Fundamental Aeronautics Program Technical Conference, Cleveland, OH, March 13-15, 2012.

4) “Core Noise: overview & upcoming LDI combustor test,” Lennart S. Hultgren, Acoustics Technical Working Group Meeting, Hampton, VA, October 23-25, 2012.

5) “Liner Technology Research Progress,” Michael G. Jones, Acoustics Technical Working Group Meeting, Hampton, VA, October 23-25, 2012.

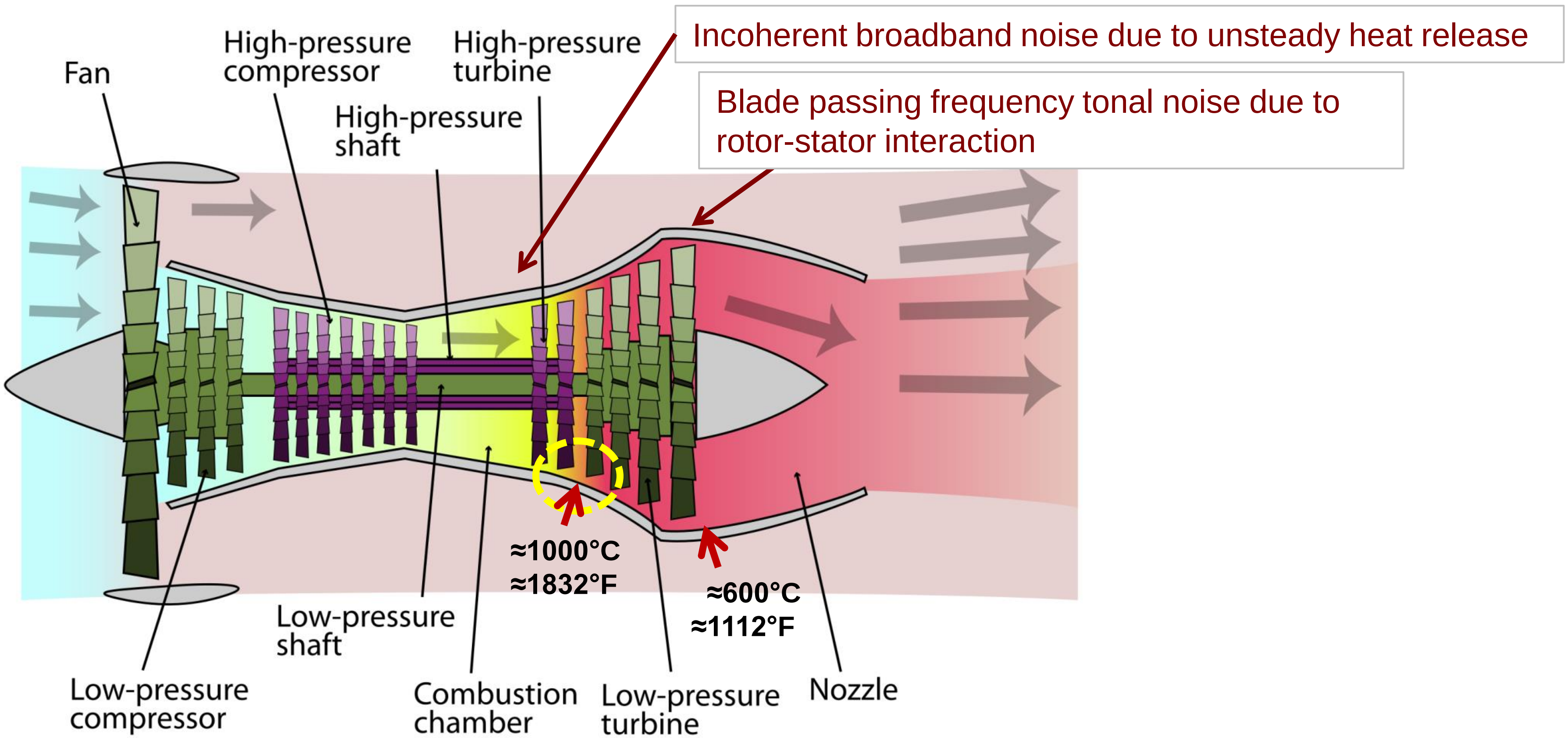
Compact, Lightweight, Ceramic Matrix Composite Based Acoustic Liners for Reducing Core Noise

Goal

- The primary goal is a lightweight, durable device (liner) capable of reducing core noise over the frequency range of 400-3000 Hz, toward achieving NASA's N+3 goal of a 71 dB cumulative noise reduction relative to the current Stage 4 regulation.
- Minimize the thickness of the liner. This is a significant concern in the core region of the engine, where the volume available for an acoustic liner is limited.

Core Noise Sources – Combustor and Turbine Noise
… Potential Acoustic Liner Locations To Be Determined

Primary Goal: develop an acoustic liner capable of reducing broadband core noise in hostile internal engine environment



Potential acoustic liner locations for addressing core noise

Compact, Lightweight, Ceramic Matrix Composite Based Acoustic Liners for Reducing Core Noise

Approach

- Define alternate CMC acoustic liner approaches that avoid the problems associated with (1) Helmholtz resonators and (2) conventional liners consisting of honeycomb sandwich structures where all of the cells have a similar length.
- Initial approach being investigated builds on an existing oxide/oxide CMC honeycomb sandwich structure manufactured by ATK COI Ceramics, Inc.

Oxide Fiber/Oxide Matrix CMCs:
Properties/Max. Use Temperature

Candidate CMCs—for fabrication of acoustic liners

Property	AS-N312	AS-N720	A-N720	AS-N650	AS-N610
Composite Density (gm/cc)	2.30	2.60	2.73	2.80	2.83
Nominal Fiber Volume (%)	48	45	45	39	51
Open Porosity (%)	24	25	25	25	25
RT Tensile Modulus (GPa)	31	76	70	96	124
RT Tensile Strength (MPa)	124	220	169	261	365
Short Beam Shear (MPa)	9.0	14.3	12.5	-	15.0
Thermal Expansion (10^{-6}/°C)	4.8	6.3	6.0	8.0	8.0
Maximum Temperature (°C)	650	1100	1200	1000	1000
Key: AS – Aluminosilicate matrix: A – Alumina matrix					

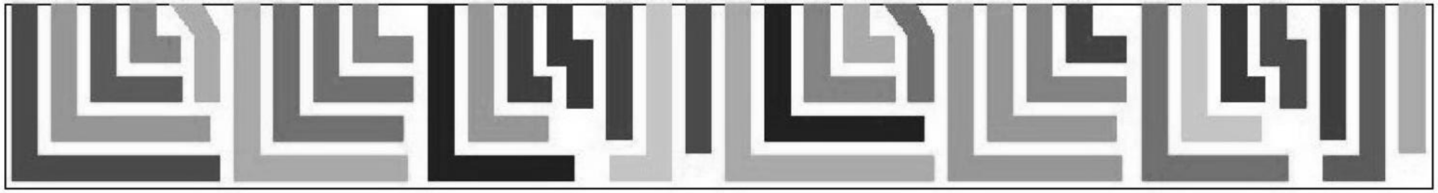
Various candidate oxide/oxide CMC materials available for use from 600 - 1200°C

Source: ATK COI Ceramics, Inc. website
http://www.coiceramics.com/pdfs/3%20oxide%20properties.pdf

Compact, Lightweight, Ceramic Matrix Composite Based Acoustic Liners for Reducing Core Noise

Approach

- ***Concept:*** Modify existing CMC honeycomb basic structure to create a range of effective cell lengths that can reduce noise over a range of frequencies (various approaches previously demonstrated using other materials, Refrs. 6, 7).



Example:
Refr. 7

- Modeling will help guide the liner design.
- Demonstrate increased Technology Readiness Level (TRL) through development and testing of appropriate subelements/test articles.

References

6) "Novel Applications of Acoustic Liners", Michael G. Jones, ARMD Fundamental Aeronautics Program Technical Conference, Cleveland, OH, March 15-17, 2011.

7) "Development and Validation of an Interactive Liner Design and Impedance Modeling Tool", Brian M. Howerton, Michael G. Jones, and James L. Buckley, 18th AIAA/CEAS Aeroacoustics Conference (33rd AIAA Aeroacoustics Conference), Colorado Springs, CO, June 4-6, 2012. AIAA 2012-2197

Helmholtz Resonator

- Used to reduce lower frequency noise.
- Volume of the cell/chamber is sufficiently large to allow absorption of the lower frequencies.
- *Limitation:* Can lead to insufficient volume available for liner components targeting the higher frequencies.

$$f = \frac{c}{2\pi}\sqrt{\frac{S}{VL}}$$

f: frequency in Hertz (Hz) where maximum absorption occurs

c: speed of sound in meters per second (m/s)

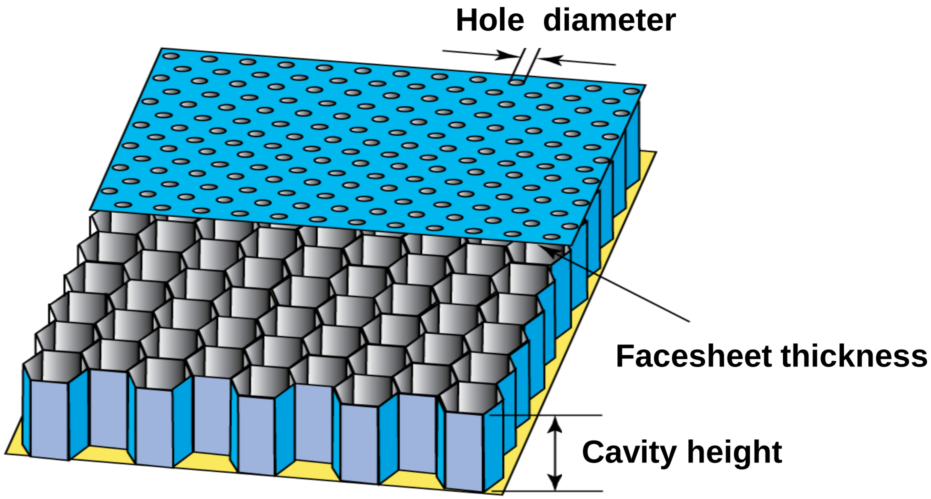
L: thickness of the facesheet in m

S: surface area of the orifice in m^2

V: volume of the air within the cell in m^3

Conventional Passive Liner Treatment

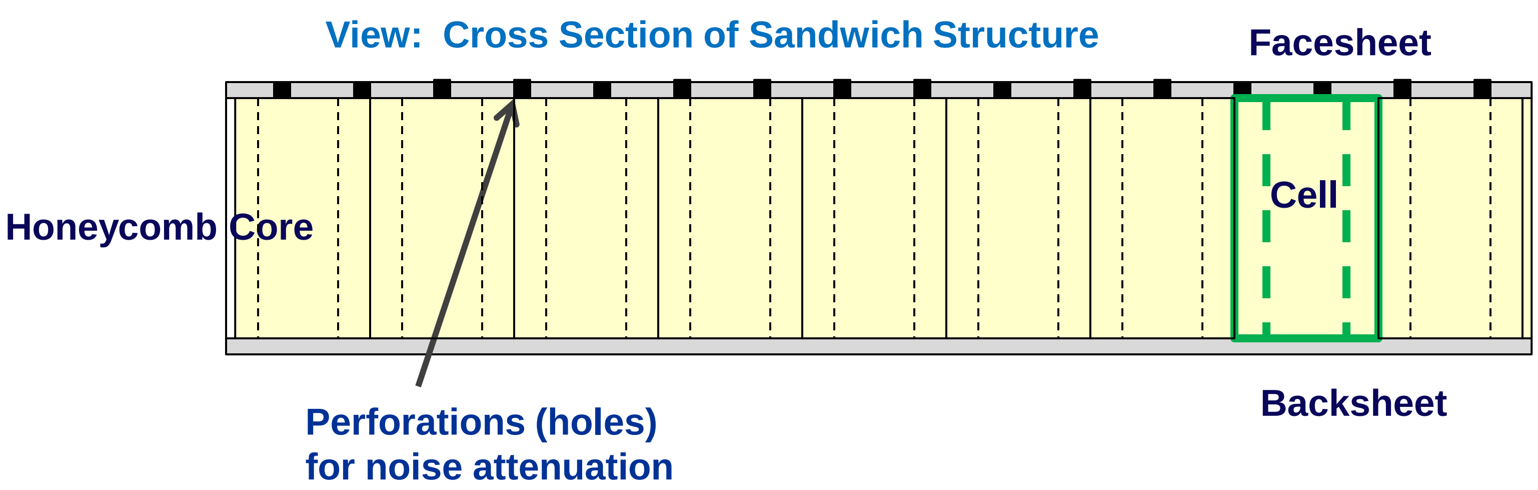
- Conventional, passive liners generally consist of a honeycomb core bonded between a porous facesheet and an impervious backplate.



- Hexagonal or honeycomb geometry is of strong interest due to the improved strength that it provides.
- Configuration produces an array of independent, one-dimensional, tuned waveguides (cells) that behave as local-reacting absorbers.
- *Limitation:* Acoustic absorption spectra: characterized by a single peak at the system resonance frequency and its odd harmonics with significantly reduced absorption at other frequencies.

Conventional Liner Architecture
Influence of Geometry/Structure on Performance

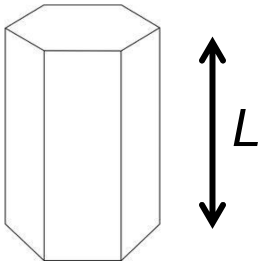
- The cell cavity height and width control the frequency at which maximum absorption occurs.
- Facesheet geometry (i.e., thickness, hole diameter, and porosity) controls the amount of acoustic absorption that will occur.
- Increased facesheet thickness can contribute to noise reduction and provide increased strength and impact resistance.
- However, increased facesheet thickness also increases the weight of the liner, as does increased liner depth.



Quarter-Wavelength Resonator

The frequency that is absorbed by a quarter-wavelength resonator (e.g., a liner cell) is defined by:

$$f = \frac{c}{4L}$$



f: frequency in Hertz (Hz) where maximum absorption occurs

c: *s*peed of sound in meters per second (m/s)

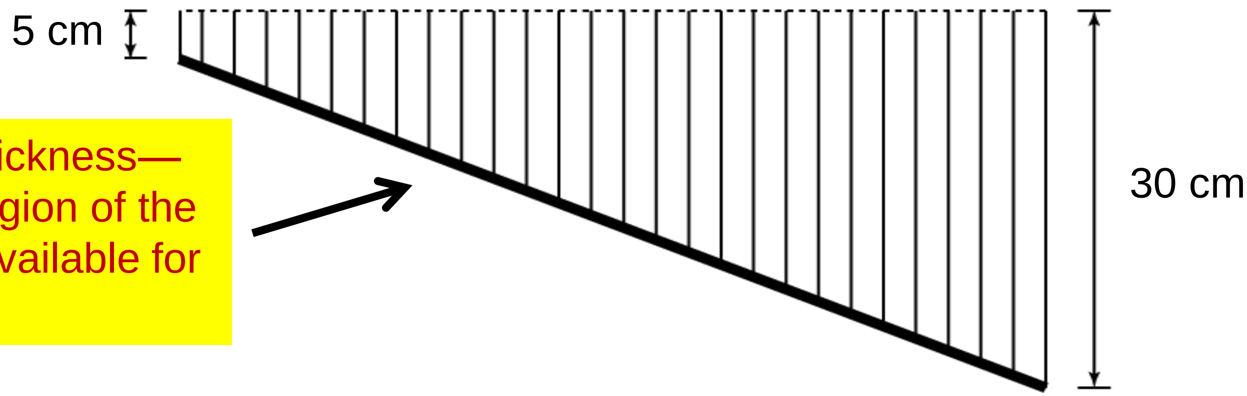
L: length of the cell in meters (m)

Example: At 900°F (482°C)—
and c = 551 m/s*:
for L = 5 cm, f = 2755 Hz;
for L = 30 cm, f = 459 Hz

*** http://www.sengpielaudio.com/calculator-speedsound.htm**

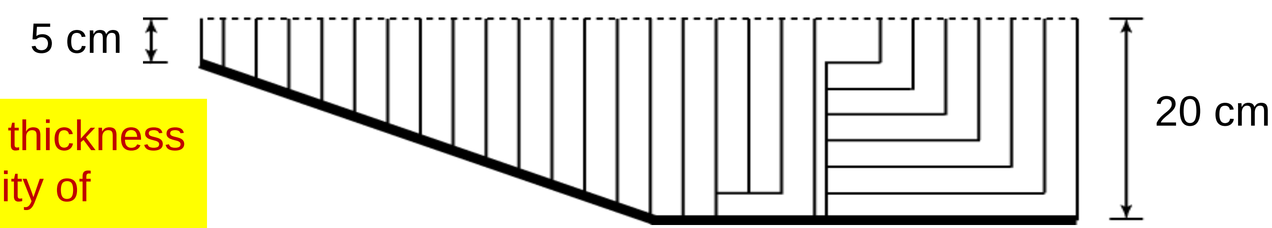
Broadband Noise Reduction

- **Variable channel lengths can provide noise reduction over a range of frequencies, because the cavity height controls the frequency at which maximum absorption will occur.**



Unacceptable/impractical thickness—given concern in the core region of the engine, where the volume available for an acoustic liner is limited

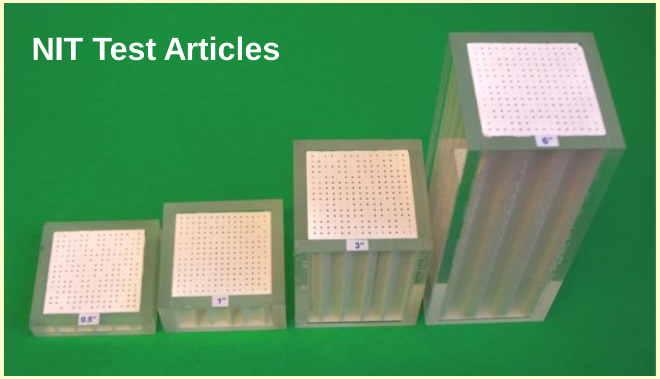
- **Changing the configuration of the channels by angling the cells or using curved or bent cells with the required effective length can significantly reduce the liner depth, while still providing nearly the same performance.**



Significantly reduced thickness increases the feasibility of utilizing this type of liner

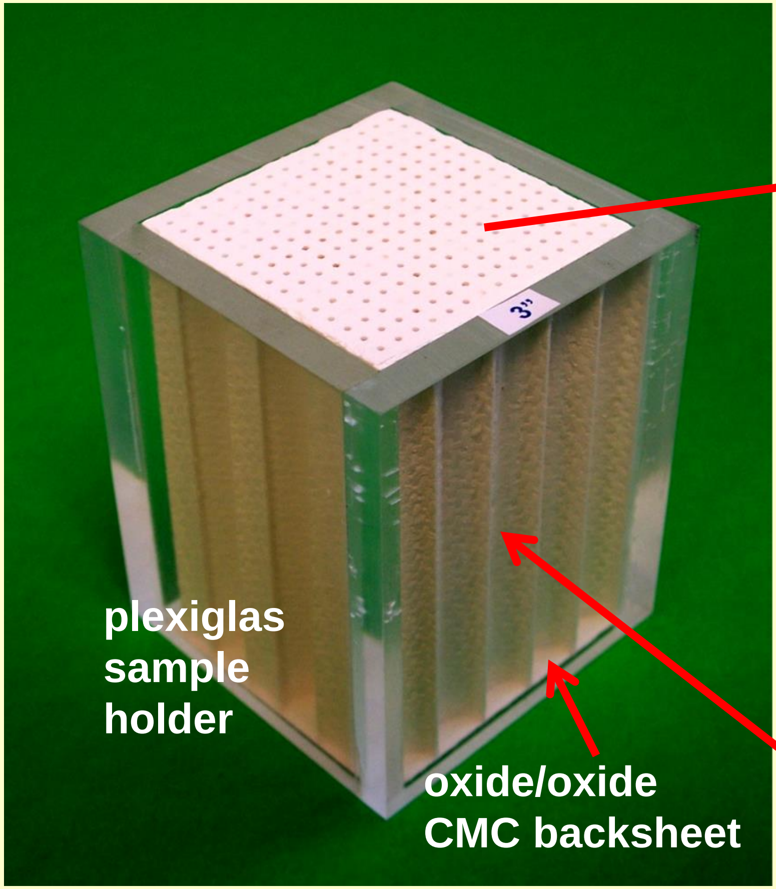
Ox/ox CMC Honeycomb Sandwich Structure Test Articles

- ATK COI Ceramics, Inc. fabricated the following CMC (ceramic matrix composite) honeycomb sandwich structures with perforated CMC facesheets for acoustic testing:
  - Four oxide/oxide 2 x 2” facesheet samples with different cell lengths for acoustic attenuation characterization at NASA LaRC via Normal Incidence Tube (NIT) testing.
  - A 16” long oxide/oxide test article with cells ranging in depth from 0.5 to 3” (1.3 to 7.6 cm) will be tested at NASA LaRC via Grazing Flow Impedance Tube (GFIT) testing.

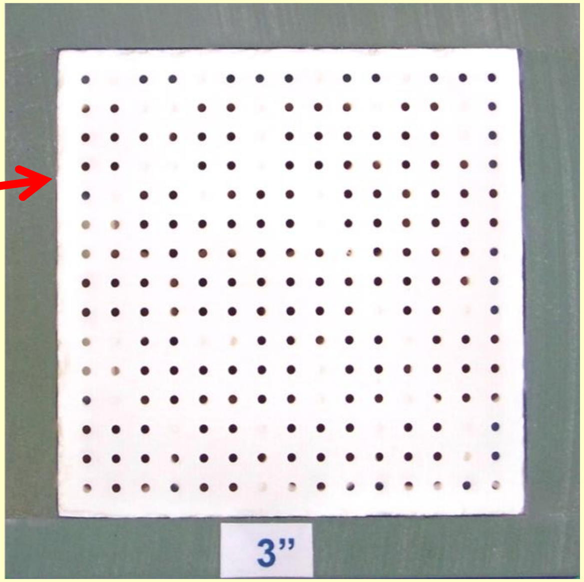


Acoustic Performance Characterization

CMC Test Article for the NASA LaRC Normal Incidence Tube (NIT)



3” depth NIT test article**



2 x 2” perforated oxide/oxide CMC* facesheet

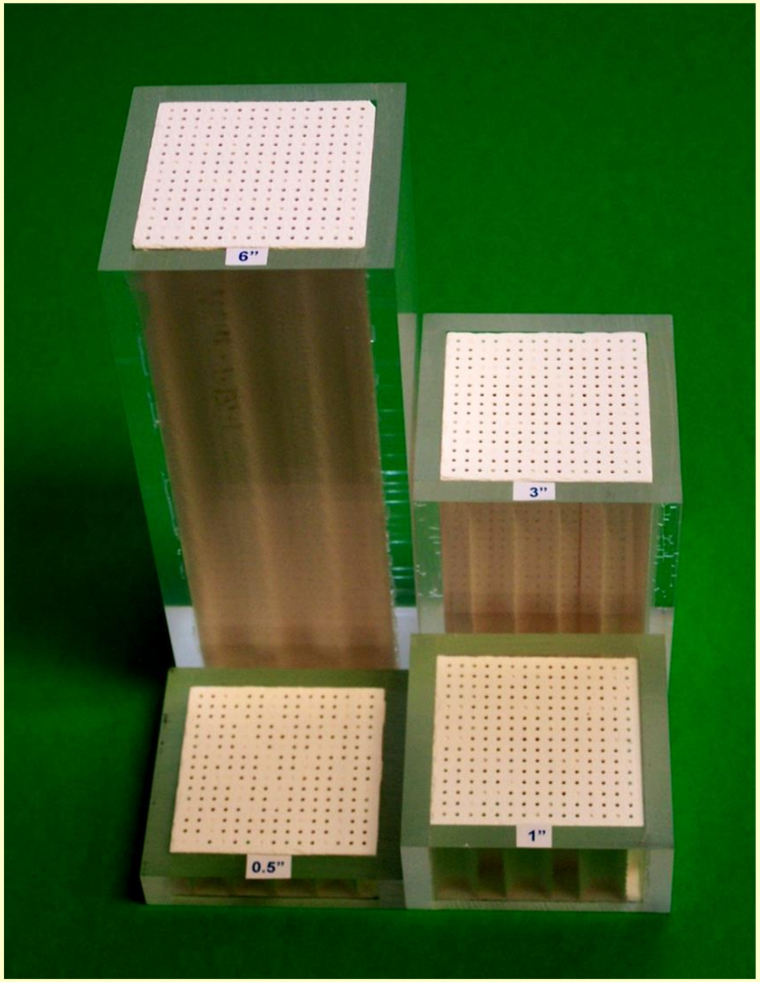
oxide/oxide CMC honeycomb core

*** CMC (ceramic matrix composite)**

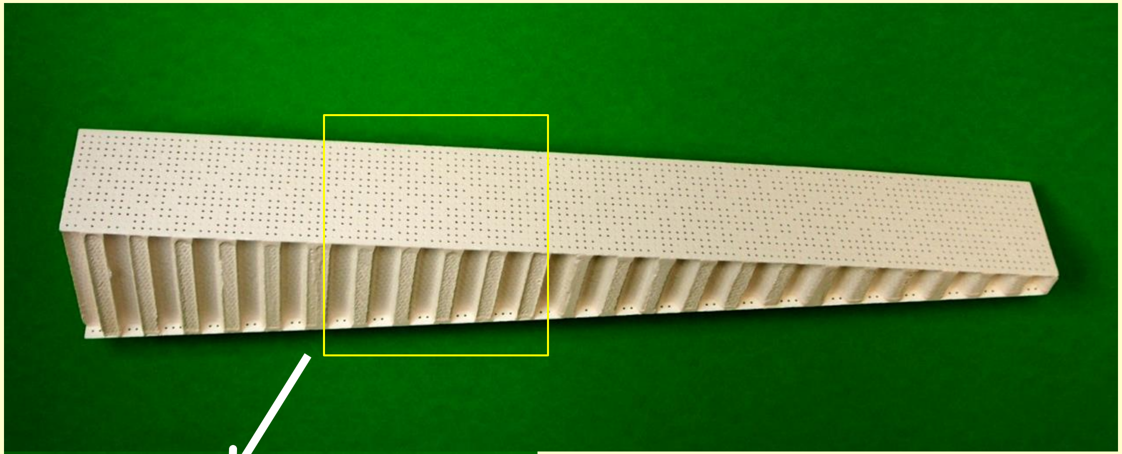
**** Fabricated by COI Ceramics, Inc.**

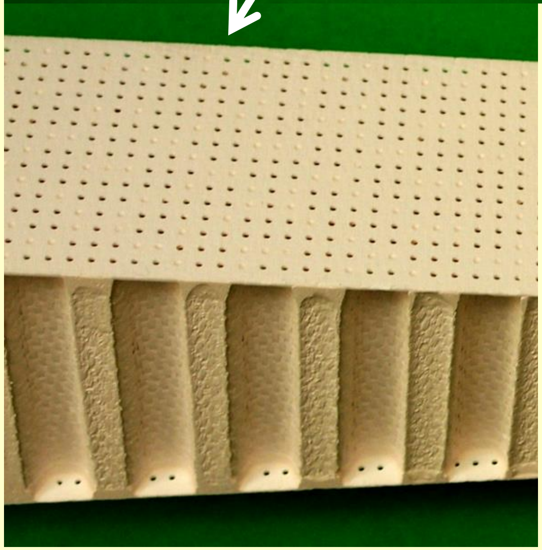
Acoustic Performance Characterization

CMC Test Articles** for the NASA LaRC Acoustic Liner Test Facilities*



Test articles for Normal Incidence Tube (NIT) - 0.5”, 1”, 3”, and 6” depth





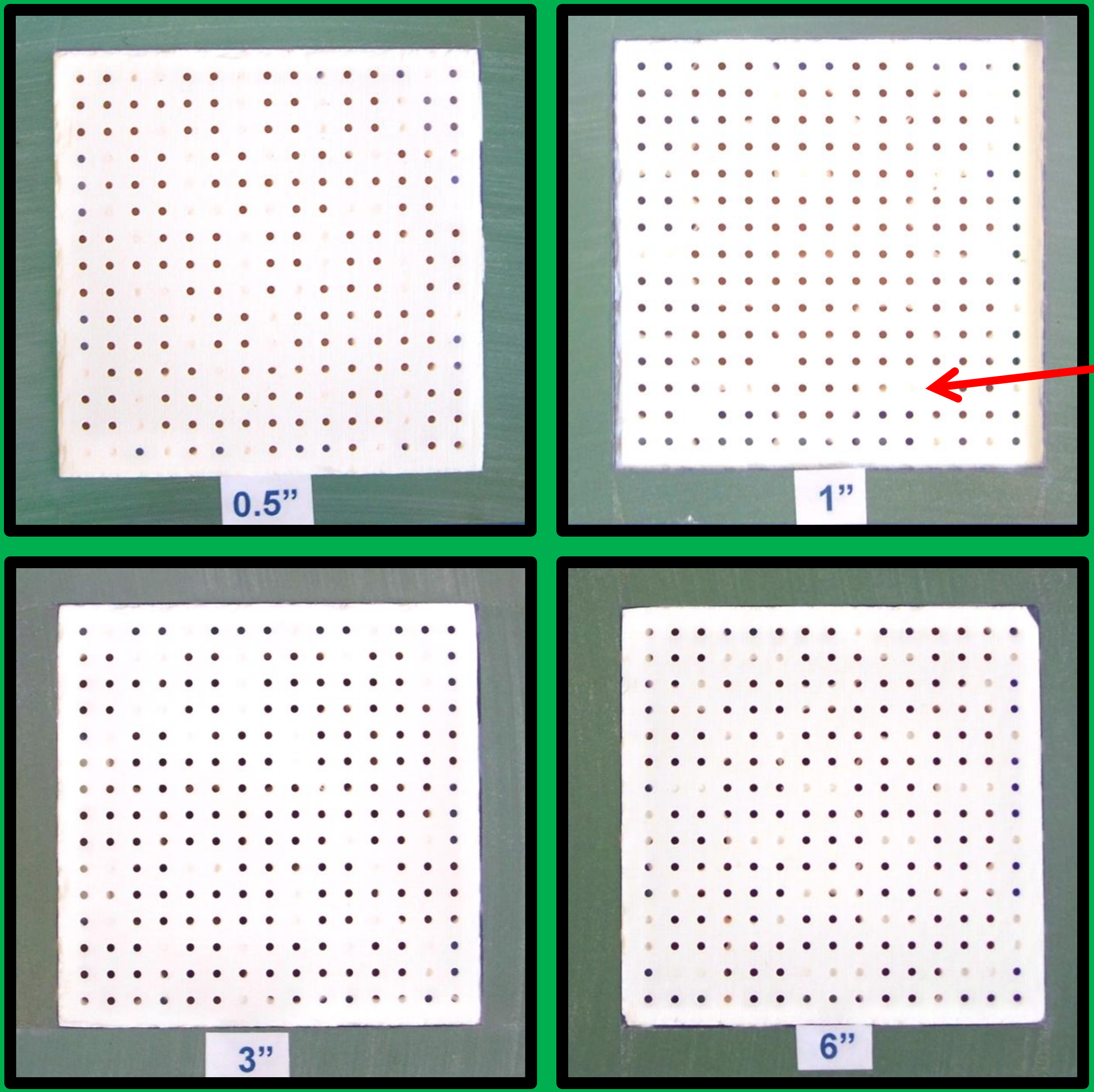
Test article for Grazing Flow Impedance Tube (GFIT)

- *16” length*
- *0.5 to 3” depth*
- *For demonstration of acoustic absorption over a range of frequencies*

*** CMC (ceramic matrix composite)**
**** Fabricated by COI Ceramics, Inc.**

Acoustic Performance Characterization

*CMC** Test Articles for the NASA LaRC Normal Incidence Tube (NIT)*



Top View—
Perforated oxide/oxide CMC facesheets

- ***Holes spaced 0.125” apart***
- ***Full or partial blockage of holes where facesheet bonded to CMC honeycomb core***

**** Fabricated by COI Ceramics, Inc.**

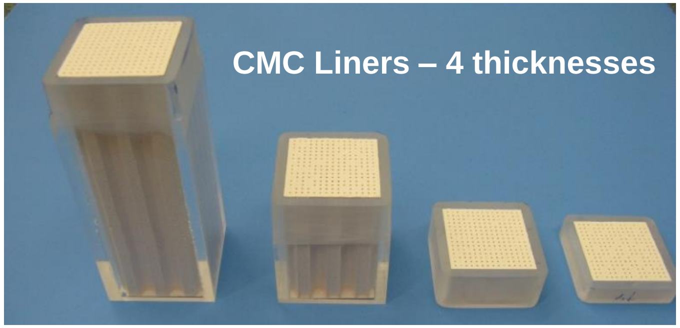
Initial Evaluation of CMC Acoustic Liner
Normal Incidence Tube Characterization

OBJECTIVES
- Initiate characterization of basic CMC (ceramic matrix composite) acoustic liner samples.
- Evaluate the conventional impedance prediction model over a realistic range of impedance spectra, to assess the effects of CMC porosity on acoustic performance.

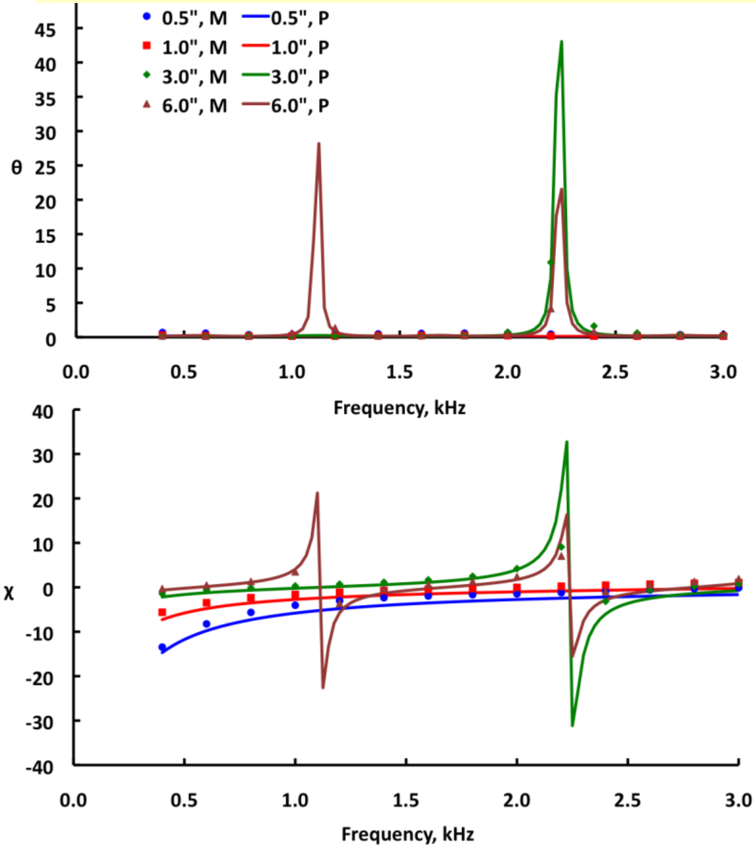
APPROACH
- Four oxide/oxide CMC liner samples with identical facesheets and honeycomb cores, with thicknesses of 0.5, 1.0, 3.0 and 6.0”, were tested in the LaRC Normal Incidence Tube.

RESULTS
- The results were used to evaluate the prediction model over a realistic range of impedance spectra.
- The measured and predicted impedance spectra (resistance, θ, and reactance, χ) compared favorably for this test condition (no flow, 140 dB).

SIGNIFICANCE
- Determined that the impedance prediction model used for conventional liners is sufficient for use with the CMC structures.
- This prediction model has been used to design a broadband CMC liner for evaluation in the Grazing Flow Impedance Tube, to investigate the effects of mean flow at ambient conditions.



Measured vs Predicted Impedance Spectra



Potential Advantages to Using Ox/ox CMC Liner(s)

- In comparison w/uncoated SiC/SiC or SiC/SiNC CMCs, ox/ox CMC materials should provide better environmental stability from 900 - 1800°F, and lower thermal conductivity (which could minimize heat flow to surrounding structures).
- Oxide fibers are relatively inexpensive.
- The density of a candidate ox/ox composite is ≈ 2.8 g/cc (AS-N610) vs. 8.4 g/cc for IN625, potentially offering component weight reduction and reduced fuel consumption.

CMC Acoustic Liner Development—Concepts

- Concepts for increasing the effective cell height for lower frequency absorption while minimizing the overall liner height have been identified by NASA (bending the cells, interconnecting the cells, etc.).
- The acoustic liner(s) used to address core noise could consist of a combination of regions with quarter-wavelength resonators and regions w/Helmholtz resonators.
- Additional liners could be placed downstream from the initial core liner.

CMC Acoustic Core Liner Development—Future Efforts

Testing

- Grazing Flow Impedance Tube (GFIT) testing of the 16” long oxide/oxide CMC sandwich structure test article will be performed in early 2013 at LaRC.
- In the near term, concepts of interest might initially be investigated by examining test articles made via rapid prototyping prior to obtaining CMC samples.
- Follow-on activities could include characterization of CMC test articles up to 6000 Hz and at higher temperatures to further the development of the technology.
- The durability (thermal shock, thermal fatigue, etc.) and manufacturability of CMC liners are critical issues that must be evaluated at some point.
- NASA is investigating the availability of suitable high temperature test rigs—for characterizing acoustic liners that show great potential. The goal is to eventually demonstrate TRL 5 for a compact core liner (broadband absorber).

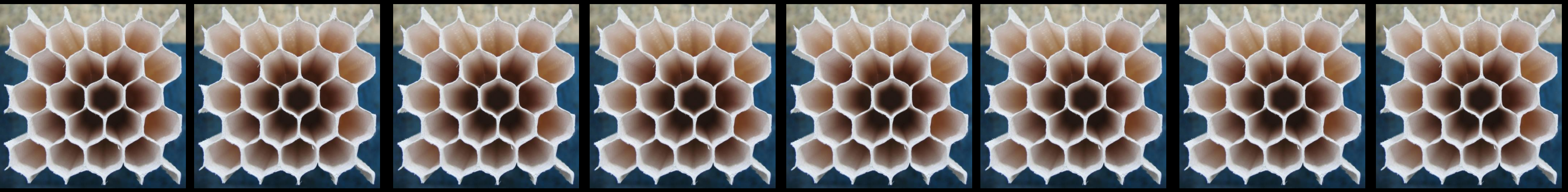
CMC Acoustic Core Liner Development—Future Efforts

Design and Teaming

- The performance of the proposed acoustic core liner can be optimized using improved NASA design tools that will help us reduce noise over a specified frequency range.
- Collaboration with Industry and academia is welcomed.

Acknowledgments

- J. Heidmann, NASA GRC (Cleveland, OH)
- J. Riedell, ATK COI Ceramics, Inc. (San Diego, CA)
- NASA LaRC Liner Technology Facility



Appendix

Core Noise Reduction

Lennart S. Hultgren, NASA Glenn Research Center, Cleveland, OH 44135

Presented at the Acoustics Technical Working Group Meeting
Hampton, Virginia, October 18-19, 2011

Summary

This presentation is a technical summary of and outlook for NASA-internal and NASA-sponsored external research on core (combustor and turbine) noise funded by the Fundamental Aeronautics Program Subsonic Fixed Wing (SFW) Project. Sections of the presentation cover: the SFW system-level noise metrics for the 2015, 2020, and 2025 timeframes; turbofan design trends and their aeroacoustic implications; the emerging importance of core noise and its relevance to the SFW Reduce-Perceived-Noise Technical Challenge; and the current research activities in the core-noise area. Recent work[1] on the turbine-transmission loss of combustor noise is briefly described, two[2,3] new NRA efforts in the core-noise area are outlined, and an effort to develop CMC-based acoustic liners for broadband noise reduction suitable for turbofan-core application is delineated.

The NASA Fundamental Aeronautics Program has the principal objective of overcoming today's national challenges in air transportation. The reduction of aircraft noise is critical to enabling the anticipated large increase in future air traffic. The Subsonic Fixed Wing Project's Reduce-Perceived-Noise Technical Challenge aims to develop concepts and technologies to dramatically reduce the perceived aircraft noise outside of airport boundaries.

[1] Hultgren, L. S., "Full-Scale Turbofan-Engine Turbine-Transfer Function Determination Using Three Internal Sensors," AIAA 2011-2912 (2011).
[2] NNC11TA40T, "Acoustic Database for Core Noise Sources," Honeywell International, 10/19/2011.
[3] NNX11AI74A, "Measurement and Modeling of Entropic Noise Sources in a Single-Stage Low-Pressure Turbine," U. Illinois, 6/15/2011.

Fundamental Aeronautics:
Subsonic Fixed Wing
↓
Fixed Wing

CORE-NOISE RESEARCH

Lennart S. Hultgren, NASA Glenn Research Center, Cleveland, OH 44135
Presented at the 2012 Technical Conference NASA Fundamental Aeronautics Program
Cleveland, Ohio, March 13-15, 2012

Summary

This presentation is a technical summary of and outlook for NASA-internal and NASA-sponsored external research on core noise funded by the Fundamental Aeronautics Program Subsonic Fixed Wing (SFW) Project. Sections of the presentation cover: the SFW system-level noise metrics for the 2015 (N+1), 2020 (N+2), and 2025 (N+3) timeframes; SFW strategic thrusts and technical challenges; SFW advanced subsystems that are broadly applicable to N+3 vehicle concepts, with an indication where further noise research is needed; the components of core noise (compressor, combustor and turbine noise) and a rationale for NASA's current emphasis on the combustor-noise component; the increase in the relative importance of core noise due to turbofan design trends; the need to understand and mitigate core-noise sources for high-efficiency small gas generators; and the current research activities in the core-noise area, with additional details given about forthcoming updates to NASA's Aircraft Noise Prediction Program (ANOPP) core-noise prediction capabilities, two NRA efforts (Honeywell International, Phoenix, AZ and University of Illinois at Urbana-Champaign, respectively) to improve the understanding of core-noise sources and noise propagation through the engine core, and an effort to develop oxide/oxide ceramic-matrix-composite (CMC) liners for broadband noise attenuation suitable for turbofan-core application. Core noise must be addressed to ensure that the N+3 noise goals are met. Focused, but long-term, core-noise research is carried out to enable the advanced high-efficiency small gas-generator subsystem, common to several N+3 conceptual designs, needed to meet NASA's technical challenges. Intermediate updates to prediction tools are implemented as the understanding of the source structure and engine-internal propagation effects is improved.

The NASA Fundamental Aeronautics Program has the principal objective of overcoming today's national challenges in air transportation. The SFW Quiet-Aircraft Subproject aims to develop concepts and technologies to reduce perceived community noise attributable to aircraft with minimal impact on weight and performance. This reduction of aircraft noise is critical to enabling the anticipated large increase in future air traffic.

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